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METHOD OF TRANSFORMING ENERGY IN A ROTARY SCREW MACHINE OF VOLUMETRIC TYPE

FIELD OF THE INVENTION

The invention relates to a method of transforming energy in a rotary screw machine.

PRIOR ART

Volume screw machines of rotary type comprise conjugated screw elements, namely a female (enclosing) screw element and a male (enclosed) screw element. The female screw element has an inner profiled surface (inner screw surface, female surface), and the male screw element has an outer profiled surface (outer screw surface, male surface). The screw surfaces are non-cylindrical and limit the elements radially. They are centred about axes which are parallel and which usually do not coincide, but are spaced apart by a length E (eccentricity).

A rotary screw machine of three-dimensional type of that type is known from US 5,439,359, wherein a male element surrounded by a fixed female element is in planetary motion relative to the female element.

The working chambers of internally conjugated rotary volume screw machines are formed by kinematic mechanisms consisting of these male and female curvilinear elements.

The transformation of motions is based on an interconnected rotary motion of male and female elements, making mechanical curvilinear contact with each other and forming these closed working chambers for a working substance which performs an axial motion when a relative motion of conjugated elements in space is performed.

In most cases, the screw surfaces have cycloidal (trochoidal) shapes as it is for example known from French patent FR-A-997957 and US 3,975,120. The transformation of a motion as used in motors has been described by V. Tiraspolskyi, "Hydraulical Downhole Motors in Drilling", the course of drilling, p.258-259, published by Edition TECHNIP, Paris.

The effectiveness of the method of transforming energy in the screw machines of the prior art is determined by the intensity of the thermodynamic processes taking place in the machine, and is characterized by the generalized parameter "angular cycle". The cycle is

equal to a turn angle of any rotating element (male, female or synchronizing link) chosen as an element with an independent degree of freedom.

The angular cycle is equal to a turn angle of a member with independent degree of freedom at which an overall period of variation of the cross section area (opening and closing) of the working chamber, formed by the male and female elements, takes place, as well as axial movement of the working chambers by one period P_m in the machines with an inner screw surface by one period P_f in the machines with an outer screw surface.

The known methods of transforming energy in volume screw machines of rotary type with conjugated elements of a curvilinear shape realised in the similar volume machines have the following drawbacks:

- limited technical potential, because of an imperfect process of organizing a motion, failing to increase a quantity of angular cycles per one turn of the drive member with the independent degree of freedom;
- limited specific power of similar screw machines;
- limited efficiency;
- existence of reactive forces on the fixed body of the machine.

In all cases, the longitudinal axes of internally conjugated screw elements are parallel. Sometimes, they have eccentricity and some of them are movable. Either a planetary motion or a differential motion is provided.

SUMMARY OF THE INVENTION

It is an object of the invention to solve the above-mentioned problems.

A volume screw machine used in the invention comprises at least two sets of conjugated male and female elements, spaced apart from each other, preferably along a central axis of the machine. The female elements of each set have an inner profiled surface centred about a first longitudinal axis, and the male elements of each set have an outer profiled surface centred about a second longitudinal axis. The first and second

longitudinal axes are parallel to each other. The male elements are placed in a cavity of the corresponding female elements.

In the method of transforming energy in a rotary screw machine according to the invention, upon rotary motion of the male and/or female work elements, working chambers which are formed between the female and male elements perform an axial movement. In the invention, the rotary motions of the differents sets are synchronized in such a manner that synchronous and inphase motion of the elements in different sets is performed with different values of angular periods of oscillation of axial movement of said working chambers.

In other words, the parts (or elements) of the machine are arranged in such a manner that upon motion of one conjugated element, coaxial longitudinal axes in each set move with angular velocities having values characterized by a predetermined ratio (one with respect to the other one).

The synchronization helps to optimize the function of the machine.

In a preferred embodiment of the invention, the angular period decreases from one set to the next set, thereby having the working medium compressed. In an alternative embodiment, the angular period increases from one set to the next set, thereby having the working medium expanded.

An embodiment of the machine comprises both a rotor and a contrarotor, wherein the latter is rotated contrarotatively to the rotor. Planetarily moving elements can be placed in between. That embodiment facilitates a stable and balanced movement of working medium in working chambers.

The means for coupling can be a mechanical device. Alternatively, the working medium can be used to couple the different sets. In a combination of these alternatives, the means for synchronizing comprises a (at least partially) hollow shaft, wherein the working medium passes through said shaft.

In a further preferred embodiment, a first set forming a differential kinematic mechanism having three degrees of freedom of a mechanical rotation of which two degrees of freedom are independent, and a second set forming a planetary kinematic mechanism having two

degrees of freedom of a mechanical rotation of which one degree of freedom is independent are used. A third set of conjugated elements can form a differential kinetic mechanism.

The machine can then be arranged in such a manner that the conjugated elements in the first and third sets have essentially equal cross sections. In other words, the first and third sets can be of equal design and are coupled via the second set. In particular, the average radii and/or thicknesses and/or undulations of the screw elements are equal.

The sets can, of course, comprise more than a single male and a single female element. In a preferred embodiment, a nested structure is provided. For example, the above-mentioned first and second sets can comprise two groups of conjugated male and female elements which are separated by a channel in which the working medium can be transported.

In a further preferred embodiment of the method according to the invention, thermal energy of the working medium is removed and supplied in a heat exchanger (removed from the working medium in a first stage and supplied in a second stage or the other way round).

Furthermore, mechanical energy produced in one of said sets can be used to drive another mechanical device. In other words, mechanical energy can be extracted from the rotary screw machine. Of course, well-known thermodynamical laws have to be respected, in particular temperature changes will have to occur at the same time in some portions of the machine or the working medium.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more apparent from the description of a preferred way of performing it which is given below with respect to the drawing, in which

Fig.1a shows a longitudinal cross section of the volume screw machine used in the present invention,

Fig.1b shows a schematic view of the volume screw machine of Fig. 1,

Fig.2 shows a cross section along the lines II-II in fig.1 of the volume screw machine of Fig. 1,

Fig.3 shows a cross section along the lines III-III of fig.1 of the volume screw machine of Fig. 1,

Fig.4 illustrates the principle how an end profile of a screw surface of anyone of the conjugated elements can be designed,

Fig.5 presents an electronic CAD construction of a screw surface of the conjugated element having a symmetry order of n_m=4.

DESCRIPTION OF A PREFERRED EMBODIMENT

A volume screw machine used in the present invention, which is shown in Figs.1a and b, comprises three different sets of conjugated elements, namely a first set 1 forming a differential kinematic mechanism intended for suction and for compressing of air, a second set 2 forming a planetary mechanism intended for compression of air (and for providing fuel combustion in a chamber 140 thereof) and a third set 3 forming a differential kinematic mechanism which is intended for expansion of combustion products from the chambers 140 of set 2.

In other words, the volume screw machine used for the invention is a rotary screw internal combustion engine in which a motion is transformed and in which a continuous-cyclic change of working substance energy takes place in synchronism to a process of passing that working substance through working chambers of the different sections. The volume screw machine therefore generates working substance energy. There are synchronizers 11 and 14 provided which are intended to support the operation of set 1 and set 3, respectively. They can be provided as a single element as shown in Fig. 1b.

It is to be noted that the different sets 1, 2 and 3 of the volume screw machine according to the invention are spaced apart from each other along the central axis Z of the machine. In other words, the sets 1, 2 and 3 do not surround each other. Rather, they are placed one behind the previous one, or, in other words, one in the line of the previous one. They are all centred about the central axis of the machine.

The different sets are coupled by both a mechanical link and by the action of the gaseous working substance, i.e. a gaseous link. The mechanical link between the mechanisms 1, 2 and 3 is provided by a common shaft 4 which is partially hollow and is further provided with a crank 10 attached thereto. Air can pass from the mechanism set 1 into the mechanism set 2 through the hollow portion of the shaft 4. The sets 1 and 2 together form a rotary screw compressing machine (compressor) of

volumetric type. The set 2 provides for combustion chambers 140, and sets 2 and 3, when cooperating, form a rotary screw expanded machine (detander) of volumetric type.

Both the first and the second sets 1 and 3 comprise two groups of conjugated elements, namely a first group of elements 5, 6 and 7 (5′, 6′ and 7′) and a second group comprised of elements 15, 16 and 17 (15′, 16′ and 17′).

It is to be noted that the first set 1 and the second set 3 are essentially of equal shape, i.e. have equal cross sections. This is in particular the case with the single screw elements: They have the same average radii and the same thicknesses.

The details are as follows:

The first set comprises first female elements 5 and 15 having an inner profiled surface 105 and 115, respectively, wherein these female elements 5 and 15 are centred about a fixed axis Z, the symmetry axis of the volume screw machine. The female elements 5 and 15 have a symmetry order of 6. In the following, the notion symmetry order relates to a rotational symmetry of an end surface of these elements. The first set further comprises second elements 6 and 16 which are both male and female, i.e. comprise both an outer trochoidal surface 216, 116 and an inner trochoidal surface 206, 106. They have a symmetry order of 5 and are centred about an own axis O_6 and O_{16}, respectively. They execute a planetary motion. Synchronizer elements 7 and 17 having an outer profiled surface 207 and 217, respectively, with a symmetry order of 4 are further provided. Between these elements, working chambers 100, 300 on the one hand and 200 and 400 on the other hand are provided. Between the elements 5, 6 and 7 on the one hand and 15, 16 and 17 on the other hand, a channel is provided such that air which is transported in the working chambers 100 and 200 can be returned to the (in fig.1) lower side of the volume screw machine and then be further transported in the working chambers 300 and 400.

The second set 2 comprises only two conjugated elements, namely a female element 8 having an inner profiled surface 108 with a symmetry order of 3 which is also centred about the axis Z, and a male element having an outer profiled trochoidal surface 209 with a symmetry order of 2, which is centred about the axis O_9 and which executes a

planetary motion. Working chambers 140 are formed between these elements. Fuel can be inserted via the inlet 12 into these working chambers 140.

The third set 3 comprises in each group a first male element 7′ and 17′, respectively, having outer surfaces 207′ and 217′, respectively, with a symmetry order of 4, which are centred about the fixed axis Z. Second elements 6′ and 16′ which are both male and female and comprise initial trochoidal surfaces 106′, 206′ and 116′, 216′, both having a symmetry order of 5. These elements 6′ and 16′ are centred about second axes $O_{6'}$, $O_{16'}$ and execute a planetary motion. The elements 5′ and 15′ having inner surfaces 105′ and 115′ with a symmetry order of 6 act as synchronizer-elements. Between these elements, working chambers 100′, 300′ on the one hand and working chambers 200′, 400′ on the other hand are formed.

The set 1 shown in Fig.1 which forms a differential mechanism has the three degrees of freedom of the mechanical rotation of the elements 5, 6, 7 and 15, 16, 17. Two of these degrees are independent degrees of freedom of a rotation.

The same applies to the elements 5′, 6′, 7′ and 15′, 16′ and 17′ of the set 3 forming a differential mechanism as well.

The planetary kinematic mechanism of transforming a motion of set 2 shown in fig.1 has the two degrees of freedom of mechanical rotation of the element 9. One degree thereof is an independent degree of freedom of a rotation.

In the invention, the transformation of energy may be realized by transforming a motion of the conjugated elements in the form of mechanically connected motions of elements of sets of groups of kinematic mechanism, namely those formed by the conjugated elements 5, 6, 7, 15, 16, 17, and 8, 9 which are disposed coaxially to the eccentricity in the internal cavities of each other. Moreover, the synchronizing coupling links 10 can be used as well as matching devices 11 which execute synchronized interconnected motion of the elements about the machine main axis and about their own axes. In order to do so, the motion transformation is performed in synchronism, at least, in two groups of kinematic mechanisms, wherein a motion of inter conjugated elements is transformed in order to receive working substance energy.

The method according to the invention facilitates it to carry out a transformation of a motion of conjugated elements in synchronism and simultaneously, whilst working substance is passing through the differential kinematic mechanisms in the set 1, which are mechanically connected to each other and are for instance forming a suction and a compression section as shown in Fig. 1. At least this differential kinematic mechanism formed in set 1 has three degrees of freedom of a mechanical rotation, of which the two ones are independent, and the planetary kinematic mechanisms of the set 2 shown in Fig. 1 comprises a section of compression and emission of a working substance having one independent degree of freedom of rotation, wherein in the differential and planetary mechanisms, different values of the angular periods of an axial movement of the working chambers are provided (when counted from a turn angle of the output link 4).

It is to be noted that the screw elements cannot be of arbitrary shape but have to have well-defined properties. Their well-defined shape d_m which is constructed in the following manner as explained with respect to fig.4 in which the profile d_m has a symmetry order of $n_m=5$:

One starts with the construction of a hypocycloid Γ which has the parametric form (dependent on parameter t):

$$x(t)=E\cos(n_m-1)t+E(n_m-1)\cos t$$

$$y(t)=E\sin(n_m-1)t-E(n_m-1)\sin t.$$

Such hypocycloids Γ of a symmetry order n_m, (n_m+1), (n_m+2), ... (n_m+i) are those curves which are described by a point A of a circle having the radius $O_{1A}=E$ and the centre O_E and which has been rolled (without sliding) along the inner surface of another circle with radii equal to En_m, $E(n_m+1)$, $E(n_m+2)$, ... $E(n_m+i)$ having a centre O_m as it is shown in fig.1. The points where the point A contacts these circles are indicated at B, C, D, F, I. An equivalent way of constructing such a hypocycloid Γ of a symmetry order n_m, (n_m+1), (n_m+2), ... (n_m+i) is based on describing the curve the point A of circles with radii $E(n_m-1)$, $E(n_m+1)$, ... $E(n_m+1+i)$ and centre O_2 which roll (without sliding) along the inner surface of circles having radii equal to En_m, $E(n_m+1)$, $E(n_m+2)$, ... $E(n_m+2+i)$.

The profile D_m used for the screw elements in the present invention is, starting from the hypocycloid Γ, obtained by rolling a circle with radius r_0 which is for example equal to 2E, $r_0=FR=2E$ in fig.4, along

the hypocycloid Γ, wherein during the rolling, the centre of that circle moves along the hypocycloid.

If r_0 is chosen to vary monotonally along the z-axis (the axis perpendicular to the plane of the drawing in fig.1), one obtains for the profile D_m the parametric equations (dependent on parameter t):

$$x(t)=E\langle \cos[(n/(n+1))[\arcsin(\sin t)-t]]+n \cos[(\arcsin(\sin t)-t)/(n+1)\rangle +r_0(z)\cos[\arcsin(\sin t)-(\arcsin(\sin t)-t)/(n+1)];$$

$$y(t)=E\langle \sin[(n/(n+1))[\arcsin(\sin t)-t]]+n \sin[(\arcsin(\sin t)-t)/(n+1)]\rangle +r_0(z)\sin[\arcsin(\sin t)-(\arcsin(\sin t)-t)/(n+1)];$$

wherein $n=n_m-1$ or $n=n_f-1$.

Fig.5 shows a three-dimensional representation of a screw element obtained by using the construction described above.

All of the outer surfaces 217, 216, 207, 206, 217', 216', 207', 206', 209 of the male elements 17, 16, 7, 6, 17', 16', 7', 6' and 9 and all of the inner surfaces 105, 106, 115, 116, 105', 106', 115', 116', 108 of the female elements 5, 6, 15, 16, 5', 6', 15', 16' and 8, respectively, are radially limited by such non-cylindrical screw surfaces constructed as explained above. It is to be noted that the symmetry order of these surfaces increases from the interior to the exterior. In the second set, the screw element 9 has a symmetry order of 2, whereas the screw element 8 has a symmetry order of 3. In the first set 1 and the third set 3, the innermost element 17, 17' has a symmetry order of 4 and is surrounded by an element 16, 16' with a symmetry order of 5 which itself is then surrounded by an element 15, 15' having an inner profiled surface 115, 115' with a symmetry order of 6. This series of symmetry orders is then repeated starting from the element 7, 7' to the element 5, 5'.

The elements 5, 7, 15, 17, 5', 7', 15', 17' are set such that they can rotate about the axis Z. The axes O_6, O_{16}, $O_{6'}$, $O_{16'}$, O_9 of the elements 6, 16, 6', 16' and 9, respectively, are movable. It is to be noted that the axis O_6 has an eccentricity of $E_1=E$ with respect to the central axis Z, and that the axis O_{16} has an eccentricity of $-E_2$ (less than E_1) with respect to the central axis Z. These axes O_6 and O_{16} are placed on a line traversing the central axis. During rotation, their spatial relationship remains conserved. In other words, if the eccentricities are chosen in such a manner as to obtain a statically balanced volume screw machine, the screw machine is also dynamically balanced. The elements 6, 16 and 9 are

set in the machine such that they can execute a planetary motion about the axis Z. The elements 6, 16, 6', 16' are set between the elements 5, 7; 15, 17; 5', 7' and 15', 17', respectively, without any additional means to start the rotors into a planetary motion. The rotor 9 is hinged on a crank 10 of shaft 4.

In the differential mechanisms 1 and 3 and the planetary mechanism 2, the links are set such as to make possible the performing of volume continuously-cyclic suction with compression in the set 1, compression with release of working substance in working chambers 140 of the set 2 and expansion of the working substance and the working chambers 100', 200', 300', 400' of the set 3. It is to be noted that the combustion section with combustion chamber 140 is formed by the elements of the planetary mechanism 2, a cross section of which is shown in fig.3. The planetary mechanism 2 consists of the central fixed stator 8 and the planetary rotor-satellite 9, the crank 10 at the shaft 4. The device 12 is intended for injection of fuel into the chamber 140 and for providing its ignition. The combustion chambers 140 may be formed by one period of birotative twist of the profiles of the elements 8 and 9 or two periods of the twist (for fuel combustion at constant volume).

With fixed element 8, the planetary motion of the element 9 is defined by the following parameters:

$\omega_8=0$, symmetry order $n_8=3$; $n_9=2$; $\omega_1=\omega_{revolution(9)}=1$; $\omega_9=\omega_{swivelling(9)}=-0.5$. The total volume in set 2 is given by $V_2=(3\cdot V_{140}\cdot 360/360)=3V_{140}$ for rotation of the shaft 4. In each set, the rotation of the female screw elements 8 about the central axis may be carried out. Alternatively, the element 8 may be stationary. A planetary motion of the male screw element 9 conjugated with the first one may be carried out with the help of the synchronizing coupling link-crank 10 or a third (male) conjugated screw element which is coaxial to the first one.

Turning now to the first set, one can choose three kinds of state of the first group of elements 5, 6 and 7:

a) The rotation (or state of immobility) of the first element 5 about the central fixed axis and the rotation (or state of immobility) of the third element (synchronizer) 7 about the central fixed axis,

b) A revolution of the axis O_6 of the second element 6 about the fixed central axis, and

c) Swivelling of the second element 6 with the help of the synchronizing coupling link (male conjugated screw element 7) which is coaxial to the first one.

These three kinds of state can be (mechanically) synchronized each with the respective one of the second group of elements 15, 16 and 17 of the first set 1, comprising:

d) The rotation (or state of immobility) of the first element 15 about the central fixed axis and the rotation of third element (synchronizer) 17 about the central fixed axis,

e) A revolution of the axis O_{16} of the second element 16 about the fixed central axis, and

f) Swivelling of the second element 16.

The angular cycle T_i of a pair of female-male conjugated elements is given by equation:

$$T_i = \frac{2\pi}{n_{m,f} \left| (\omega_f/\omega_I) - (\omega_m/\omega_I) \right|}$$

where:

ω_f, ω_m – own angular velocities of female and male elements about their own centers;

ω_I – angular velocity of an independent element e.g. an element executing a revolution and a turn angle of which defines the value of T_i;

$n_{m,f}$ – symmetry order,

$n_{m,f}$ as for a hypotrochoid scheme with outer envelope and n_f is for an epitrochoid scheme with inner envelope.

The differential motion (comprising a planetary motion of the elements 6 and 16 and a rotation of the elements 15, 15 and 17, 17) in the set 1 is defined by the following parameters:

$\omega_{ro(5, 15)}=1$; $\omega_{ro(7, 17)}=-1$; $(\omega_{ro(7, 17)}-\omega_{re(6, 16)})/(\omega_{ro(5, 15)}-\omega_{re(6, 16)})=n_{5, 15}/n_{7, 17}$ and $\omega_{re(0-6), (0-16)}=(\omega_{ro(5, 15)}n_{5, 15}-\omega_{ro(7, 17)}n_{7, 17})/(n_{5, 15}-n_{7, 17})=(6+4)/(6-4)=5$; $(\omega_{s(6, 16)}-\omega_{re(6, 16)})/(\omega_{ro(5, 15)}-\omega_{re(6, 16)})=n_{5, 15}/n_{6, 16}$ and $\omega_{m(6, 16)}=\omega_{s(6, 16)}=(\omega_{ro(5, 15)}-\omega_{re(6, 16)})(n_{5, 15}/n_{6, 16})+\omega_{re(6, 16)}=(1-5)(6/5)+5=0.2$.

The total volume of the working chambers 100, 300 driving a rotation of the shaft 4 is given by $V_{T(100)}=6V_{100}360/90=24V_{100}$ and $V_{T(300)}=6V_{300}360/90=24V_{300}$.

The total volume of the working chambers 200 and 400 during a rotation of the shaft 4 is given by $V_{T(200)}=5V_{200}360/75=24V_{200}$ and $V_{T(300)}=5V_{300}360/75=24V_{300}$.

Turning now to the third set 3, it is to be noted that the differential motion with fixed elements 7′, 17′, the rotation of the elements 5, 15′ or 5′, 15′ with an angular velocity given by the reducer 18 from the shaft 4 (independent motion), and the planetary motion of the elements 6′, 16′ (dependent motion) is defined by the following parameters:

$\omega_{5', 15'}=\omega_{ro(5', 15')}=1/3$; $\omega_{ro(7', 17')}=0$; $\omega_{re(0-6', 0-16')}=(\omega_{ro(5', 15')}n_{5', 15'})/(n_{5', 15'}-n_{7', 17'})=2/(6-4)=1$, and $\omega_{s(6', 16')}=(\omega_{re(5', 15')}-\omega_{re(6', 16')})/(n_{5', 15'}/n_{6', 16'})+\omega_{re(6', 16')}=(1/3-1)(6/5)+1=0.2$.

The total volume in the working chambers 100′ and 300′ of the set 3 during a rotation of the shaft 4 is given by $\omega_{T(100')}=6V_{100'}2\pi/3\pi=4V_{100'}$ and $V_{T(300')}=6V_{300'}2\pi/3\pi=4V_{300'}$.

The total volume of the working chambers 200′ and 400′ during a rotation of the shaft 4 is given by $V_{T(200')}=5V_{200'}2\pi/2.5\pi=4V_{200'}$ and $V_{T(400')}=5V_{400'}2\pi/2.5\pi=4V_{400'}$.

From the above, it is evident that in the case of a differential motion of the elements, the angular cycle may, according to the invention, be varied by changing relative angular velocities of the motion of screw elements forming working chambers. The angular cycle can be 90 degrees in set 1, 360 degrees in set 2, 540 degrees in set 3. In other words, it may be decreased (thereby compressing a working medium) and it may be increased (thereby according to the invention expanding a working medium). Then, the efficiency of the method according to the invention can be increased.

The direction of the axial motion of the working medium along the Z-axis in the chambers 100, 200 and 300, 400 is defined by the

direction of revolution of the centres O_6, O_{16} of the elements 6, 16 in set 1. As mentioned above, to choose the same directions of working medium motion, the revolution of the centres O_6, O_{16} is given the same direction. If one wanted to choose opposite directions of working medium motion in the chambers 100, 200 on the one hand and 300 and 400 on the other hand, the revolution of the centres O_6, O_{16} should be made contrarotatively.

In the suction set 1 with compression, the compression is carried out with working substance release (emission) into the mechanism 2. Due to the choice of the different kinematic schemes 1 and 2, the values of the angular periods of the axial motion of the working chambers counted from a turn angle of the output link 4 are different as well.

The set 1 comprised of the groups of elements 5, 6, 7 and 15, 16 and 17 forms a section of suction and preliminary compression in which continuously-cyclic stepped air compression is carried out. The group of elements 8 and 9 in set 2 ensures final compression and working substance release (emission). The working chambers 100, 200 of suction in the differential mechanism 1 are formed by the outer group of conjugated elements 5, 6, 7 which are disposed coaxially to eccentricity in the inner cavities of each other. Preliminary compression is performed when air is pumped into the inner group of conjugated elements 15, 16, 17. The synchronizing device 11 serves for driving the elements-rotors 5, 7 and 15, 17 in set 1 into rotation in different directions with equal angular velocities, i.e. contrarotatively. Simultaneously, the shaft 4 of rotor 9 in set 2 is driven into rotation. The chambers of final compression 140 in the planetary mechanism 2 are formed by the elements 8 and 9, wherein element 9 is hinged to rotate by virtue of self-synchronization on the crank 10 of the shaft 4. The other element 8 is fixed.

The interrelationship of the rotary motions of the elements 5, 7 and 15, 17 in set 1 and 9 in set 2 to the rotary motions of the elements 5′ and 15′ in set 3 (hinged to rotate in the fixed body 13) about the central axis Z is ensured by a rigid mechanical connection of the elements 5′, 15′ to the shaft 4 in set 3 by virtue of the synchronization device 14 having a transmission ratio of 3, a hinged connection of the element 9 with the shaft 4 in set 2, and a mechanical connection of the elements 5 and 15 (hinged to rotate in fixed body 13) in 1 with the shaft 4 by virtue of the

synchronizing device 11 which is an inverter of the rotary direction having a transmission ratio of -1. The element 8 (stator) in set 2, the element 7′, 17′ (stators in set 3) are mechanically rigidly connected to the fixed body 13. A mechanical connection of the elements 5′, 15′ in set 3 (hinged to rotate in fixed body 13) with the shaft 4 is made by virtue of the synchronization device 14 which is a reducer of rotary motion having a transmission ratio of 3.

In parallel to the provision of the synchronization of the rotation of the elements inside of the differential mechanisms 1 and 3, a synchronization of a rotation between the groups of differential and planetary mechanisms 1 and 3 on the one hand and 2 on the other hand is ensured. It is also possible to synchronize the rotations of the elements of the planetary and the differential mechanism through alternation of the symmetry orders of the elements of all the groups in 1, 3 or 2.

The choice of a number of transformation groups and the scheme of how the planetary and differential kinematic mechanisms are combined is determined by the required angular extent and a combination of the values of the axial movement periods of the working chambers in-between in these mechanisms.

The operation of the engine shown in fig.1 is as follows: A gaseous constituent of a working substance of an engine (e.g., air) is inserted into the set 1 by an open left end surface of the elements 15, 16 and 17 (where arrows are shown in fig.1) of the first group. Further, it is fed to an open left end surface of the elements 15, 16 and 17 of the second group via a channel (a clearance). The above-mentioned groups of elements 5, 6, 7 and 15, 16, 17 (together with the elements 8, 9) form a rotary screw air-compressor 1 of volumetric type. Through a channel in shaft 4, compressed air is led away from the set 1 and delivered to an open left end surface of the elements 8 and 9 of the combustion set 2, namely into the combustion chamber 140. The ratio of compression is $8(V_{100}+V_{200})/V_{140}$. Following the filling of the combustion chamber 140 by the six air volumes from the compressor 1 and its closing, the device 12 injects fuel into the chamber 140 and ignites it.

In a combustion cycle at constant pressure (as a Diesel cycle), the chamber 140 may be formed during one period of a birotative twist of the elements 8 and 9, and the fuel ignition may be carried out due to air

compression. In a combustion cycle as at constant volume (as in an Otto cycle), the chamber 140 may be formed during two periods of a birotative twist of the elements 8 and 9, and the fuel ignition may take place due to an ignitor spark plug. Furthermore, the ignited fuel-air mixture is then led away from an open end surface of the elements 8 and 9 to be expanded into the expansion section 3 to an open lower end surface of the elements 15, 16, 17 and 5, 6, 7 of the set 3.

The set 3 is a rotary expanded machine (detander) of volumetric type in which the expansion process of a combustible mixture carries out a work onto the shaft 4 of the engine. If the combustible mixture is completed, it is exhausted from an upper end of the set 3 (shown by the arrows). When the shaft 4 rotates, the conjugated elements 5, 6, 7, 15, 16 and 17 in set 1 limit and move the working medium of the suction section 1 (6 chambers between the elements 5, 6 and 15, 16 and 5 chambers between the elements 6, 7 and 16, 17 along the axis Z) by moving their contacts of conjugation at the two independent degrees of freedom of contra-rotative motion of the elements 5, 7, 15, 17 in set 1 as defined by the unit 11.

When the shaft 4 rotates, the conjugated elements 8 and 9 in set 2 limit and move the three working chambers 140 of the combustion section 2 along the Z-axis by moving their contacts of conjugation at one independent degree of freedom of rotary motion of the elements 9 in set 2 as defined by a crank of the shaft 4.

When the shaft 4 rotates, the conjugated elements 5′, 6′, 7′, 15′, 16′, 17′ in set 3 limit and move the working chambers of the expansion and exhaust section 3 (6 chambers between the elements 5′, 6′, 15′, 16′ and 5 chambers between the elements 6′, 7′, 16′, 17′ in each group) along the Z-axis by moving their contacts of conjugation at one independent degree of freedom of the rotary motion of the elements 6′, 16′ in set 3. A complete cycle of the axial motion of the working chambers between the elements 5′, 6′, 7′, 15′, 16′, 17′ during one revolution of the shaft 4 in set 1 occurs four times during a rotation of the shaft 4. In other words,

$$[4(V_{100'}+V_{200'})]/[4(V_{300'}+V_{400'})] \times [4(V_{300'}+V_{400'})]/3V_{140}= [4(V_{100'}+V_{200'})]/3V_{140}.$$

The interconnected rotary motions about the main axis Z of the machine and about their own axes occur in all the sets 1 to 3 with the three degrees of freedom of a mechanical rotation.

In the engine of fig.1, the mechanically connected rotors 5, 15 and the mechanically connected contra-rotors 7 and 17 rotate simultaneously about the Z-axis in opposite directions with the same relative velocities $\omega_{(5,15)}=-1$ and $\omega_{(7,17)}=1$. The relative angular velocity ω_{re} of a line of centres O_6-O-O_{16} of the rotors 6 about the Z-axis relative to the velocity of the rotors 5, 7 is given by $\omega_{re}=5$, wherein the relative angular velocity $\omega_{s(6,16)}$ of the rotors-satellites 6, 16 about their axes O_6, O_{16} is given by $\omega_{s(6,16)}=0.2$.

The compression ratio k_1 in set 1 is determined as being the relation of the sum of the products of the total volume of the six chambers between the elements 5, 6 and of the total volume of the five chambers between the elements 6, 7 to the sum of the products of the total volume of the six chambers between the elements 15, 16 and of the total volume of the five chambers between the elements 16, 17 by a number of cycles of volume variation during one turn of the shaft 4, namely:

$$k_1=24(V_{100}+V_{200})/[24(V_{300}+V_{400})]=(V_{100}+V_{200})/2(V_{300}+V_{400}).$$

The compression ratio k_2 in the set 2 is given as being the relation of the sum of the products to a product, i.e. the first product of the total volume of the six chambers between the elements 15 and 16 in set 1 and the second product of the total volume of the five chambers between the elements 16 and 17 in the set 1 to the product of the total volume of the three combustion chambers between the elements 8 and 9 in set 2 during one turn of the shaft 4, namely:

$$k_2=24(V_{300}+V_{400})/3V_{140}=8(V_{300}+V_{400})/V_{140}.$$

The complete compression degree k of the engine is the product of the compression degrees of the sets 1 and 2, $k=k_1k_2=8(V_{100}+V_{200})/V_{140}$.

It is possible to obtain any compression ratio in the chamber 140 for the purposes of the present invention as required in different engines by choosing suitable relations of the geometrical volumes of the chambers in the sets 1 and 2. It is also possible to provide any compression mode, an adiabatic or polytrope compression mode. The realization of the chamber 140 of the two periods of birotative twist of the

elements 8 and 9 permits to carry out the combustion of fuel/air mixture on axial gas transmission from one chamber into another at constant volume. Thereby, the thermodynamic efficiency of the engine is increased.

The work of the exhaust set 3 occurs with fixed elements 7′, 17′. All conjugated elements 5′, 6′, 7′, 15′, 16′, 17′ together limit the working chambers of the exhaust section of the machine and move the same along the Z-axis by the motion of their conjugation contacts.

The mechanism of set 3 is reversible.

The degree of expansion of a working substance in set 3 is given by the geometric parameters of the conjugated elements and by the number of expansion steps. For the purposes of the present invention, it may be chosen in such a manner as to provide a complete expansion of a working substance whilst decreasing its pressure down to atmospheric pressure. Thereby, no acoustic noise is generated. In this case, the mechanical energy provided by the working substance is completely used for rotating the shaft 4.

In some other cases, in particular when driving a vehicle with drooping moment characteristic, it is worthwhile to use only some part of the mechanical energy in the set 3 and to use the remaining part of the mechanical energy in an additional expanding machine 33 of volume type (detander, similar to the detander 3) which is illustrated by the dotted line in fig.1. Its shaft 34 (also indicated by means of the dotted lines in fig.1) is not mechanically connected to the shaft 4. The mechanical energy of rotation is picked off from the output shaft 34 of the additional machine 33 according to a scheme of a two-shaft engine.

In another alternative, it is possible to use a jet thrust of combustion products from an outlet of the section 3 according to a scheme of an air-jet engine in which the compressor using the method according to the present invention is formed by the sections 1 and 2 and in which the detander using the method according to the present invention is formed by the section 3 of a rotary screw machine of volume type, wherein the fuel combustions may take place in the chambers 140 of a set 2 at constant volume, thereby increasing the engine thrust. The fuel combustion can also be carried out in external combustion chambers (not shown) which are connected to the chambers 140.

Furthermore, to use not only the mechanical energy of the working substance, but to also (completely) use the thermal energy, it is possible in a special heat exchanger (which is not shown in Fig.1) to provide an exhaust of hot gases in order to heat air which passes it from set 1 to set 2 at a constant volume, thereby increasing its pressure. It is, in the invention, therefore possible to completely use the thermal mechanical energy of a working substance in an engine and to increase its efficiency and to simultaneously provide noiseless work at the pressure and temperature of exhaust gases in the atmospheric level.

The contra-rotative rotation of the output shafts 4 and 5 in the section 1 which are set up by the inverter 11 permits the connection of the engine with contra-rotative organs such as air propellers or water vanes, contra-rotative cutting members of mowing machines, saws, crushers and so on. A connection may also be realized with a counter-rotating turbine or main rotors of an aircraft and so on.

When using the volume screw machine, that method makes it possible to carry out the transformation of a motion of conjugated elements in synchronism and simultaneously during a process of the passing of a working substance through a differential kinematic mechanism in set 1.